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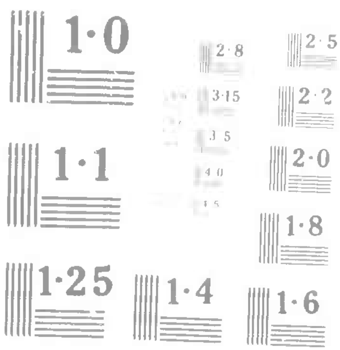

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ADVANCED ELECTRO-OPTICAL SIGNAL PROCESSING TECHNIQUES

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ABSTRACT

The studies leading to the development of an electro-optical signal processor for the Synthetic Spectrum Radar are continued. During this period the single channel experiments have been extended to the production and evaluation of photographically recorded signals.

An electro-optical system to precisely expose and evaluate photographic film is described. Amplitude transmittance versus exposure energy curves for Kodak type 2479 film are shown for parametric values of development time. These curves are used to establish the bias point exposure for the single channel recorder system. Film recordings of a 20-MHz CW signal as a function of transducer input voltage were then made.

A second coherent optical system which reads out the recorded signal is then described. The film reader output shows that a 30-dB dynamic range was obtained.

AUTHORIZATION

The research described in this report was performed at the Electronics Research Laboratories of Columbia University. This report was prepared by A. Aimette, M. Arm, M. King, E. Rothkopf and L. Schlom.

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I. INTRODUCTION AND SUMMARY OF RESULTS

One of the primary objectives of this research program is the development of an electro-optical signal processor for the Westinghouse Synthetic Radar System.[1] The optical processor system coherently records and simultaneously phase references the multi-channel radar signal output on photographic film. Subsequent processing of the recorded signals in a second coherent optical system yields directly a two-dimensional image of the target scattering centers. This technique simplifies the present processing methods and eliminates the time dilation of sequential digital computer processing systems. The development and application of advanced photorecording methods may, in fact, lead to on-line and possible real-time data processing, a significant advantage for a Space Object Identification radar.

The electro-optical signal processor under development is shown schematically in Fig. 1. This processor employs a coherent optical configuration with a 100-channel spatially multiplexed Debye-Sears light modulator cell, each modulator channel corresponding to one signal channel or range cell of the radar "range profile." The light passes through the modulator and emerges spatially phase modulated in accordance with the input signals. The integrating lens, spatial filter and imaging lens system form a moving image of all 100 signals in the light modulator on the photographic film. To record the signals on the film, the image is essentially frozen in time by amplitude modulating the input light with a signal

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[1] For numbered references see Sec.V.

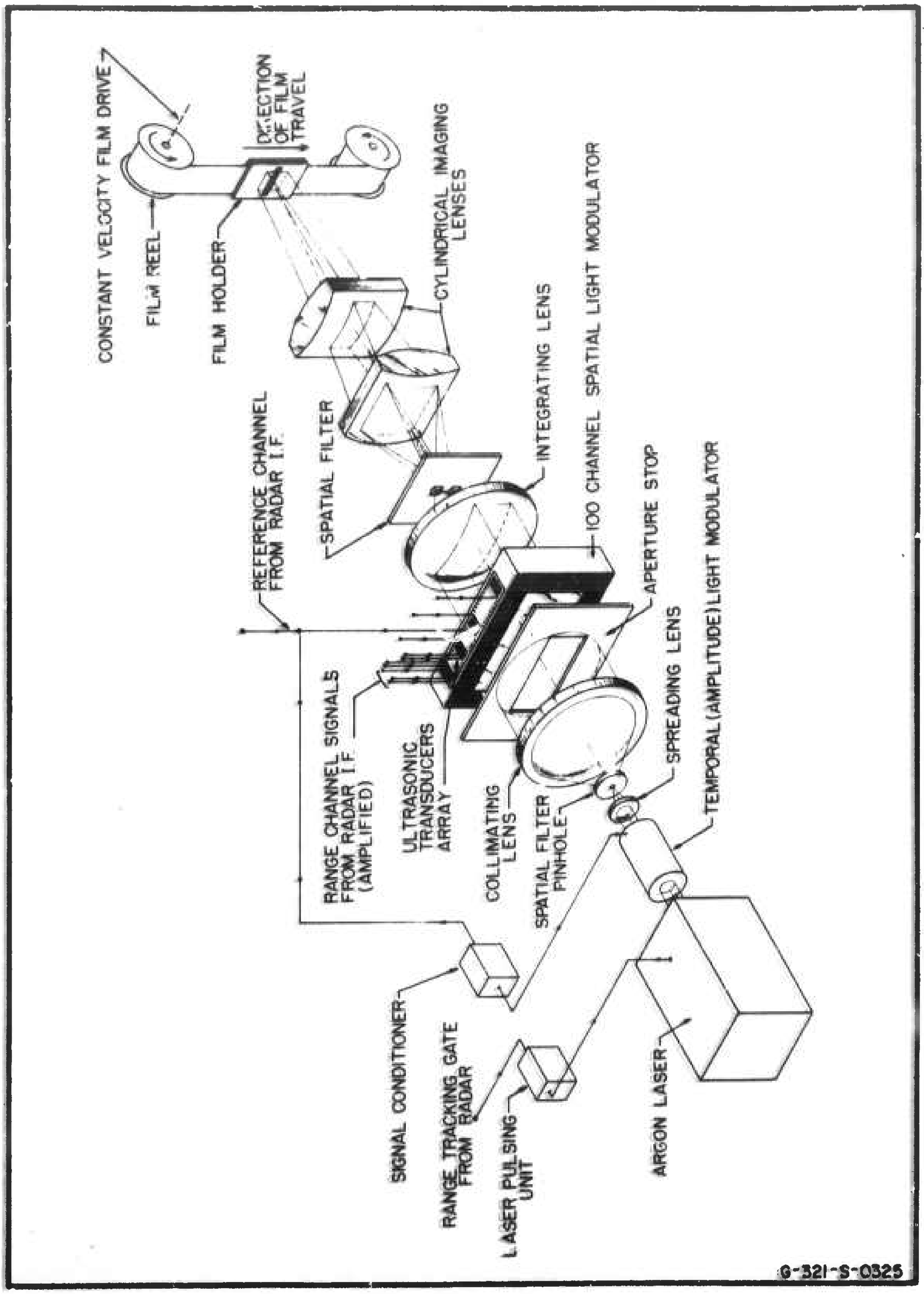

FIG. 1 SCHEMATIC DIAGRAM-ELECTRO-OPTICAL SIGNAL PROCESSOR FOR THE WESTINGHOUSE S.S. RADAR

coherently derived from one channel of the radar output. If this channel is also the "prominent point" or reference signal, it may be shown[2,3] that all 100-signal channels recorded, are thus automatically phase referenced to the prominent point signal. Note that only the signals corresponding to the "range profile" of interest are recorded since the laser light input is pulsed by a signal derived from the radar range tracking gate. To record a sequence of range profiles, the photographic film is advanced at a slow rate relative to the allowable exposure time between range profile signals. A schematic diagram of the photographically recorded signals is shown in Fig. 2.

The rows in Fig. 2 correspond to the spatially multiplexed light modulator channels and the columns correspond to the successive radar transmitted pulses. Therefore, each column represents a single "range profile" and transverse range information is recorded in corresponding rows. The incremental phase change between successive range profiles (successive columns) contains the scattering center Doppler information properly referenced to the prominent point channel. This film record can now be placed in a second optical system where coherent integration can be done between successive columns to yield directly the transverse range distance between scattering centers. The electro-optic processor, utilizing the inherent multidimensional character of optical images thus simultaneously records and phase references the radar signal output in a format suitable for directly determining the target characteristics by coherent integration in a second optical processor.

Previous reports of this program have included analytical studies of both the radar[2] and the recorder system

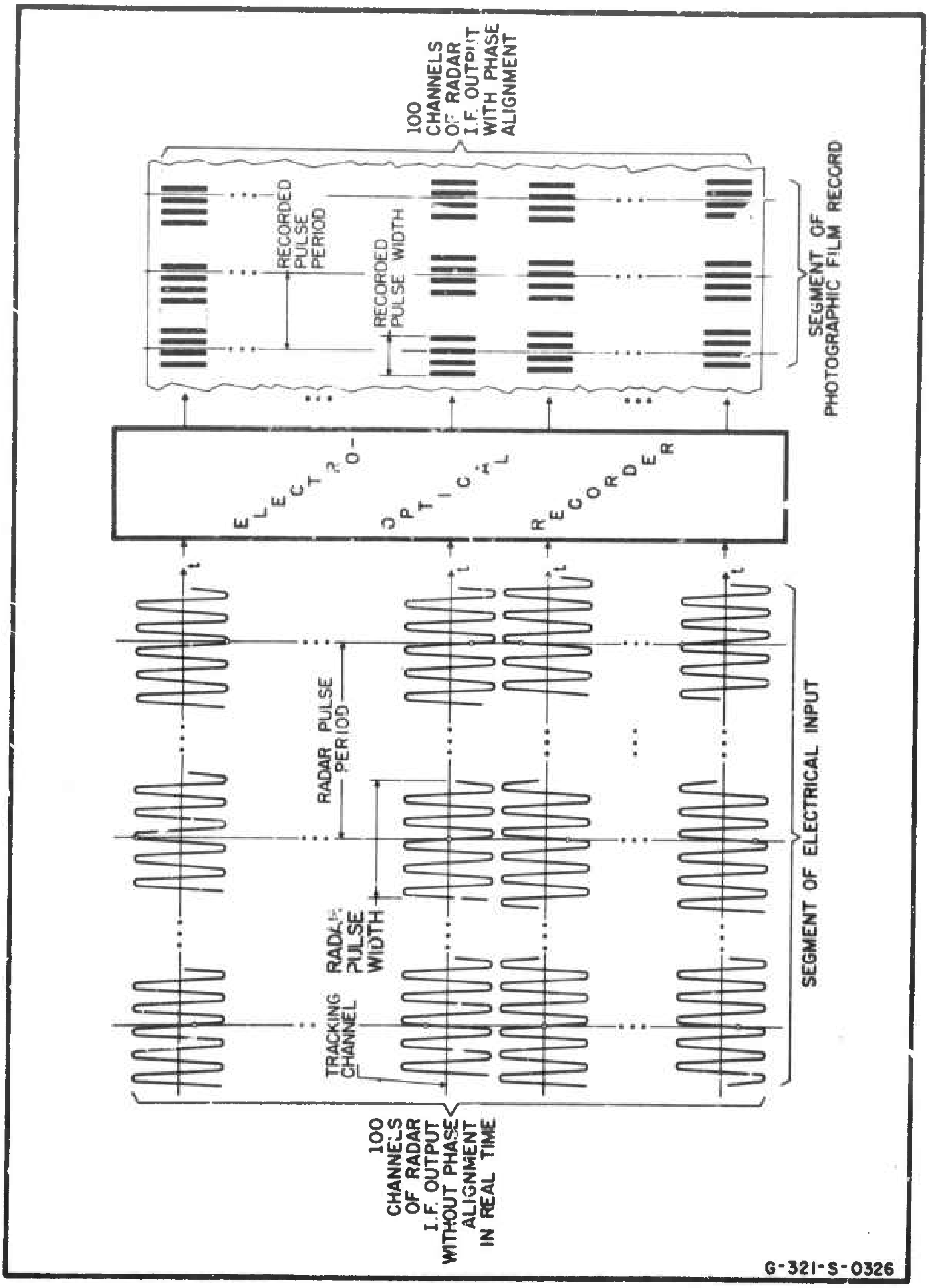

FIG. 2 RECORDER SIGNAL FORMAT — ELECTRO-OPTICAL SIGNAL PROCESSOR FOR THE WESTINGHOUSE S.S. RADAR

described above.[3] A single channel recorder system was constructed to investigate the engineering feasibility of the recorder and to determine the component requirements for an operational system. The results[4] obtained with this system verified the recorder system analysis and showed that the image plane light intensity distribution was very nearly in ideal agreement with the analytical predictions.

During this past report period, the single channel experiments were continued and extended to the production and investigation of photographically recorded signals. To determine the characteristics of various film types, an electro-optical system was constructed to precisely expose the film and to measure the intensity transmittance of the developed negatives. Since the photographic film characteristics are highly dependent on the development chemistry, a well regulated system was installed to maintain close tolerances on the development process. Amplitude transmittance versus energy exposure curves were produced and evaluated to establish the recorder bias point within the linear region of the transfer characteristic. The single channel recorder system was then utilized to produce photographic film recordings of a 20-MHz CW signal as a function of transducer input voltage. These recordings were then placed in a second coherent optical system to investigate the power spectrum of the recorded signals and thus to establish the dynamic range of the recorder system. Preliminary results show that a linear dynamic range of 30 dB was achieved using Kodak 2479 film. The grain noise spectrum of 2479 film was also measured and found to be constant over a wide range of transmittance.

During the next period, the film characteristics study will be extended to other film types. The recorder system will be modified for 30 MHz operation,the projected frequency of the final system. The recorded signals will then be re-evaluated.

The design and fabrication of a transducer array suitable for the 100-channel recorder system will be undertaken. An investigation of such factors as interchannel mechanical coupling and beam spreading interference for these small multichannel transducers is to be initiated.

An experimental stepped-transport system for cut film has been designed and is nearly completed. The design of a signal generator to simulate the Doppler shift between channels is underway, and it may be possible to demonstrate a multi-channel recorder system during this period.

II. THE EVALUATION OF PHOTOGRAPHIC FILM CHARACTERISTICS

A. INTRODUCTION

Photographic film occupies a central role in the radar signal processor since it is both a storage medium in the recorder and the signal carrier medium for further coherent optical processing. While an abundance of information about film exists in the literature, this data is primarily qualitative and oriented to conventional photographic image formation. It was therefore necessary to initiate a program for quantitative evaluation of film characteristics in a form applicable to the requirements of the processor system. This film evaluation program has three main objectives:

1. Reciprocity effects at microsecond exposure times, inherent film variations, and amplitude transmission vs exposure characteristics for various film types to control exposure in the film recorder.
2. To establish a suitable development technique to possibly enhance desired characteristics in the exposed film and
3. To monitor both the recorder system and the development system and insure reliable and repeatable photographic results.

B. THE FILM EVALUATOR - SYSTEM DETAILS

Figure 3 shows an experimental film evaluator system designed to fulfill the objectives listed above. This system serves the dual functions of a camera, for exposing the

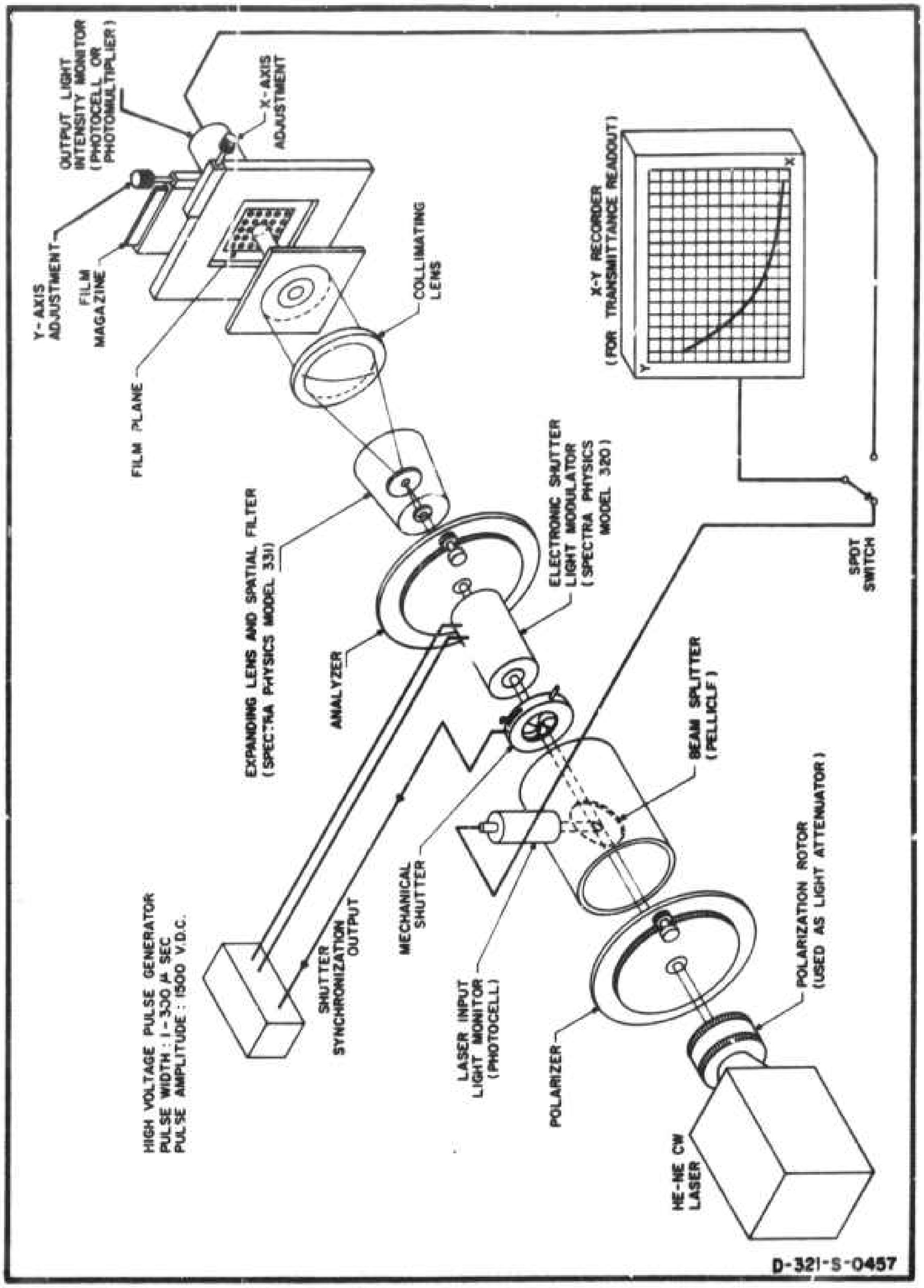

FIG. 3 FILM CHARACTERISTIC EXPERIMENTAL SYSTEM

film precisely, and as a densitometer, for determining the transmittance of the developed negative.

The system light source is a gas CW laser at 6328 Å whose intensity is adjustable by varying the polarization between the laser output beam and a fixed polarizer crystal. A beam splitter pellicle and photocell permit continuous monitoring of the input light. A combination of mechanical and electronic shutter systems provide exposure times of 1 to 300 μsec. The combination of expanding lens, spatial filter, collimating lens and camera aperture are used to uniformly illuminate a 5-mm circular spot on the photographic film. The photographic film itself is mounted on transport mechanism to permit a sequence of exposures on each film sample. For calibrating the system a photomultiplier is mounted at the film plane. When the system is used as a densitometer, a photocell is placed behind the film plane and the developed film is mounted in the camera transport system.

The operation of the system as a camera is straightforward. The shutter systems are opened and the ratio of the output photocell to the monitor photocell voltage is measured. Since the photocells are calibrated against a standard thermopile, the absolute power impinging on the film is known. A high frequency response photomultiplier is used to set the corresponding pulse width and peak light intensity levels. Since the illuminated area of the film is known, this simultaneously fixes the maximum exposure level. The film is inserted and the polarization rotator is used to divide the maximum exposure levels into equal exposure increments.

Once the film is developed, it is reinserted in the transport system plane and the shutter systems are opened. The output photocell voltage is directly read out on an x,y recorder therefore displaying the intensity transmittance of the exposed film as a function of the exposure input energy. A switch permits recalibrating the system during the test to eliminate errors caused by short term laser power excursions.

C. THE PHOTOGRAPHIC FILM

A brief survey of the photographic film currently available indicated the Kodak Rapid Access Recording (RAR) films might provide the combination of sensitivity, stability and resolution suitable for the recorder system.

These films are generally used in scientific instrumentation applications, hence their published characteristics are usually more detailed and quantitative.

Films of this series are fast, panchromatic sensitive, photorecording emulsions on a stable, 4-mil Estar(Mylar type) base. They are especially designed for rapid access machine processing and several types can be used in both the negative and reversal processing modes. Accordingly, types 2475, 2479, 2496, and 2498 were obtained in specially fabricated 4 x 5 in. cut-film format to utilize standard camera backs and film magazines. This simplified both the development and exposure mechanics.

D. EXPERIMENTAL RESULTS

The starting point for all the experimental work was the published Kodak data, suitably modified in consultation with Kodak representatives. Most of this preliminary work was performed using type 2479 film.

Figures 4 and 5 show the experimental results obtained with the system shown in Fig. 3.

Figure 4 shows the amplitude transmittance variation as a function of exposure for type 2479 film. The gray base of the film limits the maximum transmittance to about 80 per cent. This is further reduced to about 68 per cent by emulsion fog. Four curves are shown. Each film was exposed individually and the sequentially numbered pairs were developed simultaneously. These results indicate the extreme type of variations inherent in the overall exposure to read-out system and include inherent film manufacture variations. Note that slopes in the linear region about 1.0×10^{-17} joules/μ^2 are essentially identical for all test samples.

Figure 5 shows the effects of developing time variation on the amplitude transmission characteristics. Note that longer development times increase the fog level from 72 per cent at 5 min to 64 per cent at 15 min while the slope of the response curve does not increase appreciably.

Figures 4 and 5 are quite useful, since, as will be recalled, the light in the image plane of the Bragg mode recorder[4] consists of an input-voltage dependent sinusoidal light variation superposed on a constant or dc level. By adjusting the dc light amplitude to the approximate center of the amplitude transmission characteristic linear region (approximately 1.0×10^{-17} joules/μ^2) the sinusoidal light variations in the image are recorded as sinusoidal transmittance variations on the film. The next section will show the applicability of this data.

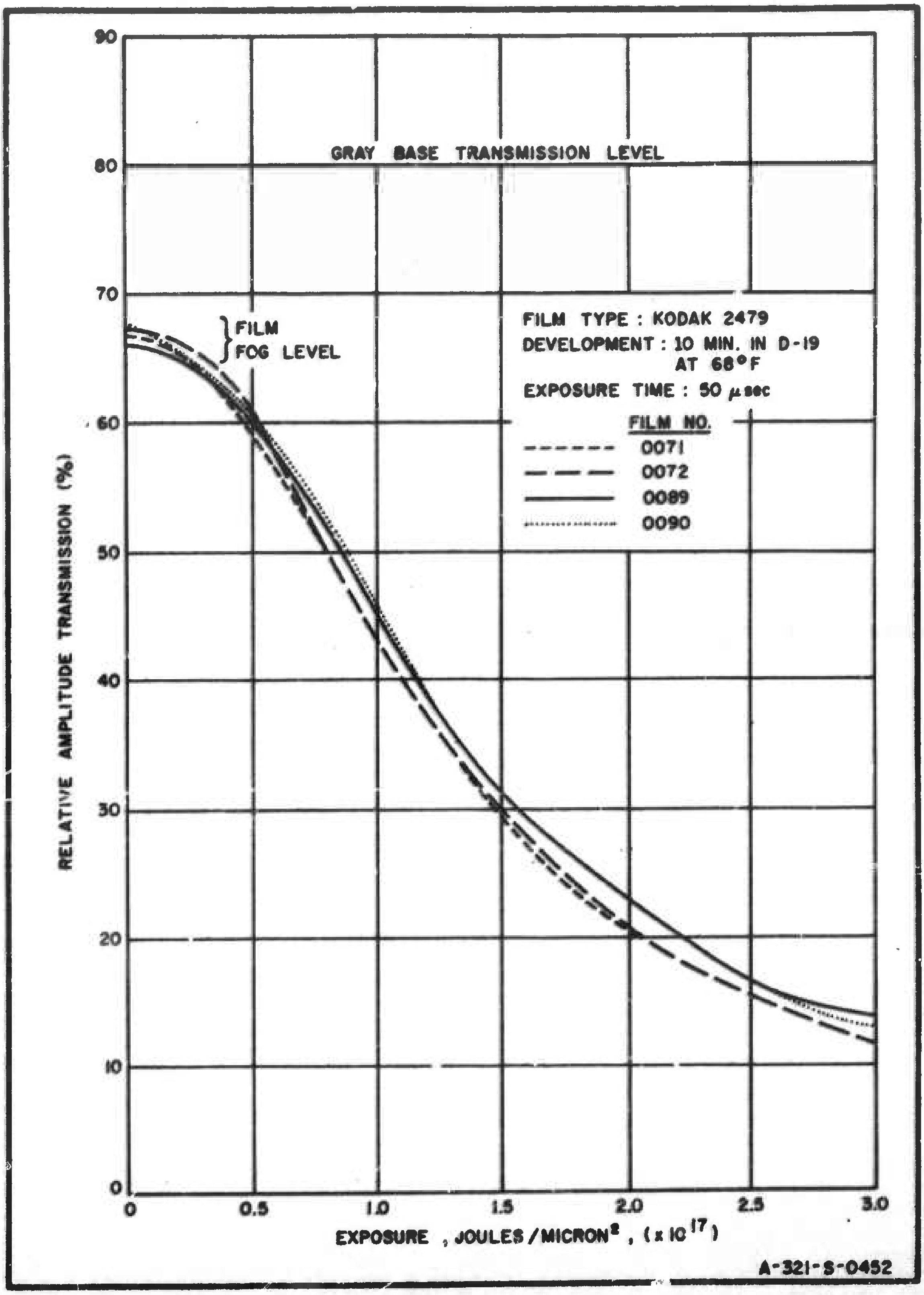

FIG. 4 MEASURED AMPLITUDE TRANSMISSION CHARACTERISTICS FOR TYPE 2479 FILM

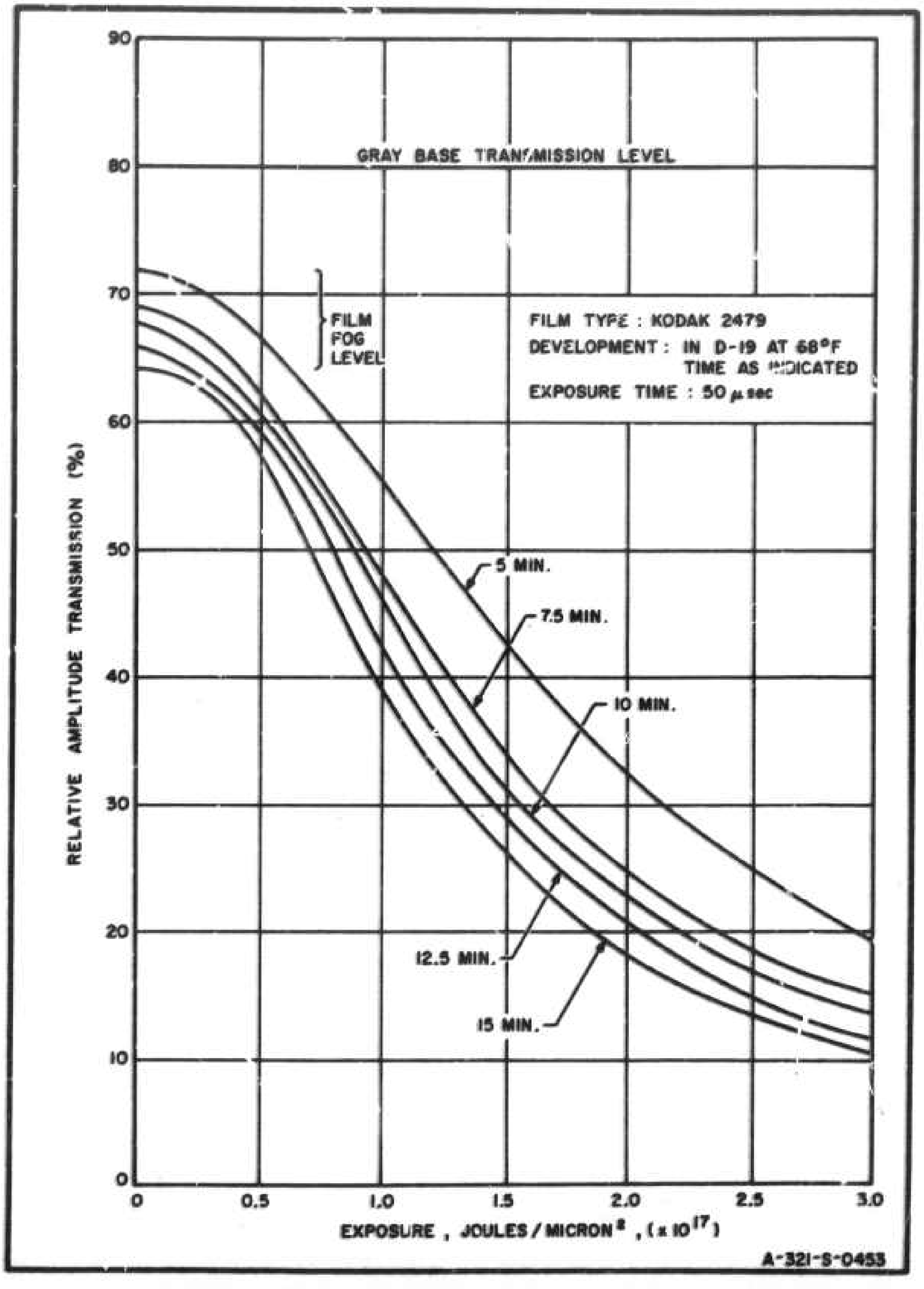

FIG. 5 MEASURED AMPLITUDE TRANSMISSION CHARACTERISTICS FOR TYPE 2479 FILM AS A FUNCTION OF DEVELOPMENT TIME

III. THE ELECTRO-OPTICAL RECORDER SYSTEM-EXPERIMENTAL RESULTS

A. INTRODUCTION AND SYSTEM DESCRIPTION

A single channel electro-optical system has been utilized to investigate the engineering problems and establish component specifications for an operational system. A schematic diagram of the system is shown in Fig. 6. The system operation is straightforward.

The laser output beam is amplitude modulated in the temporal light modulator. The combination of spreading lens, spatial filter, collimating lens and aperture stop, delineate the input light beam to a single channel ultrasonic spatial light modulator. Note that both modulating signals are coherently derived from the same 20-MHz oscillator. The acoustic wave within the spatial modulator is then imaged by the combination of integrating and imaging lens. A spatial filter in the focal plane of the integrating lens removes spurious reflections and limits low level spillover between the diffraction orders.

Figure 6 also shows the scanning system and recorder display which is used to examine the light distribution in the recorder image plane. This provides an independent technique for examining the image prior to recording it on film and also as a calibration system for setting the exposure levels. When the image is to be recorded on film, a standard press-type camera with a film transport mechanism replaces the scanning system and a mechanical shutter is used to set the exposure time.

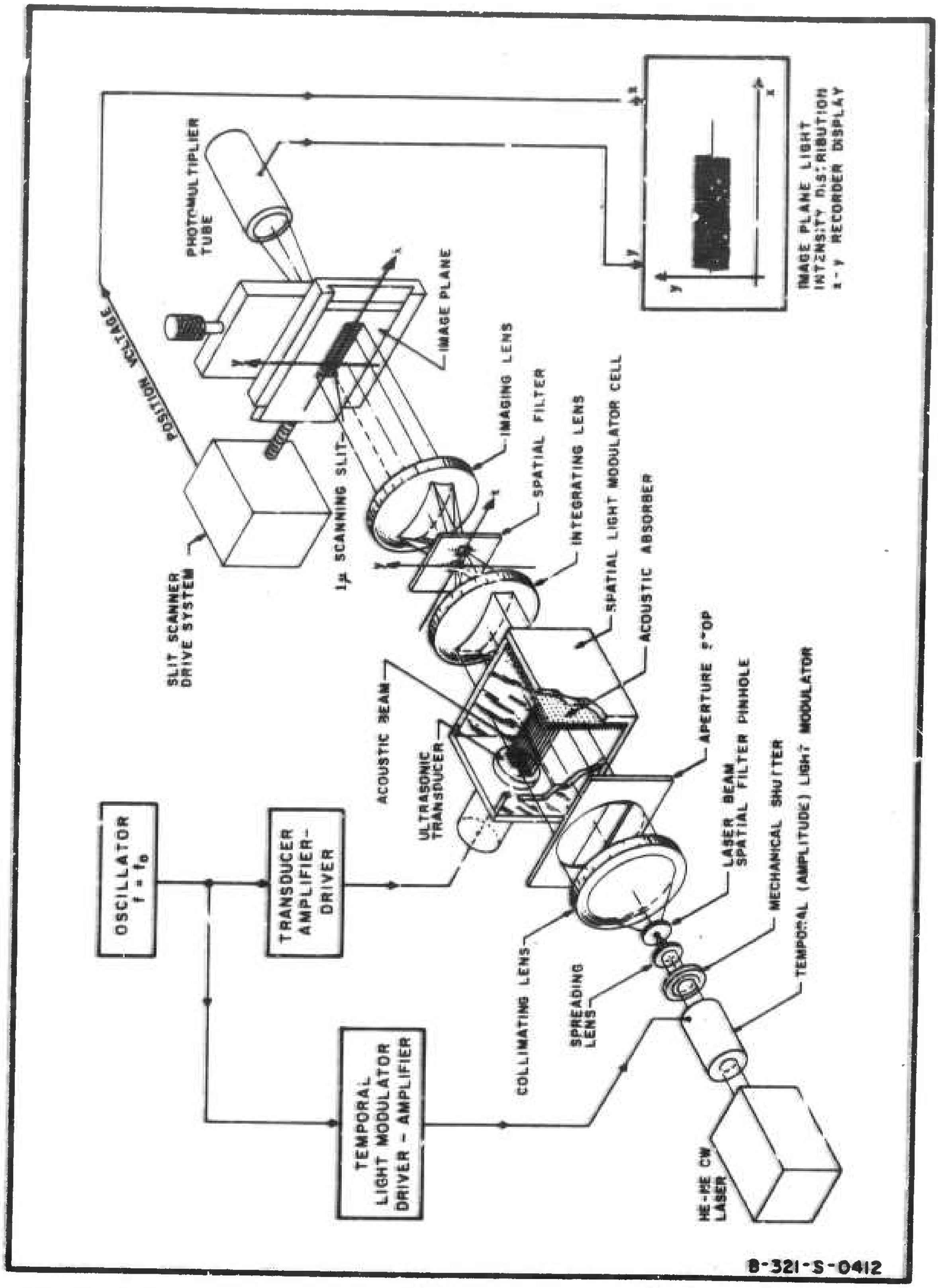

FIG. 6 SCHEMATIC DIAGRAM – ELECTRO-OPTICAL SIGNAL RECORDER EXPERIMENTAL SYSTEM

As has been reported in detail,[1,3,4] the image plane light distributions observed with this system have verified the recorder theory. Several alternate modes of operation were investigated. It was determined[4] that the Bragg mode configuration in which a sinusoidal variation proportional to the transducer input voltage spatially modulates a constant or dc light level was not only more efficient but most directly applicable to the recorder requirements. Accordingly, the experimental program during this period was limited to producing photographic film recordings with the Bragg mode system.

B. EXPERIMENTAL RESULTS

Figure 7 shows the measured light intensity distribution and the computed percentage modulation as functions of the transducer input voltage. Note that the percentage modulation is proportional to the sine of the input voltage and is nearly linear to about 6 volts.

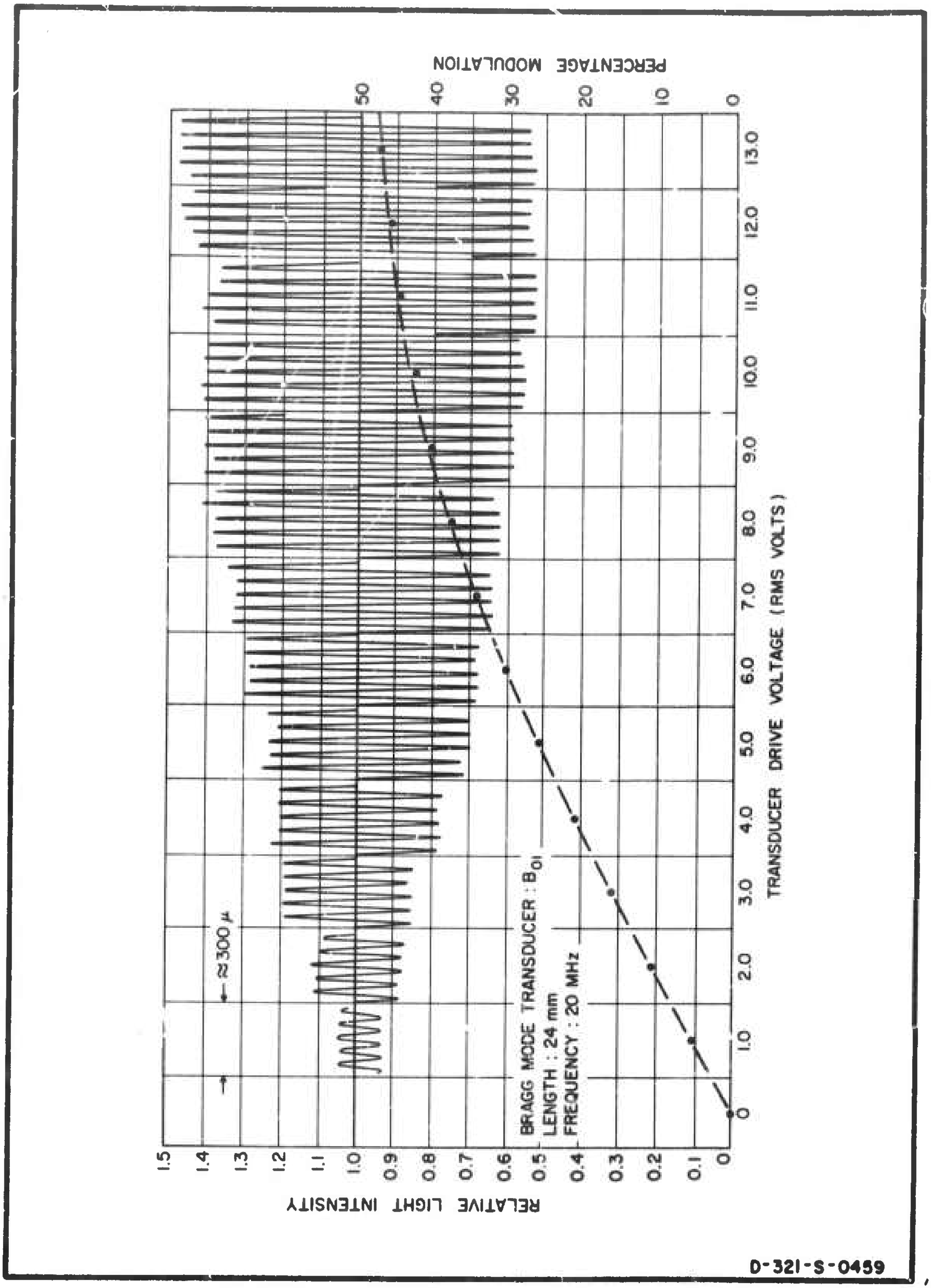

FIG. 7 ELECTRO-OPTIC SIGNAL RECORDER IMAGE PLANE LIGHT INTENSITY DISTRIBUTION FOR BRAGG MODE, B_{01}, OPERATION

IV. FILM READER SYSTEM

A. INTRODUCTION AND EXPERIMENTAL SYSTEM DESCRIPTION

The most meaningful way to evaluate the quality of test recordings of sinusoidal signals produced with the recorder is to play them back in a coherent optical spectrum analyzer. A sketch of the optical spectrum analyzer which is used as a film reader is shown in Fig. 8. The main functional components of this film reader are the gas laser, the aperture-filling and collimating lenses, the integrating lens, and the scanning slit and photomultiplier assembly. The slit and photomultiplier assembly permits detailed observation of the spectrum of an object placed in the collimated region. As an example of the operation of this spectrum analyzer, let us assume that a transparency containing in its transmittance a sinusoidal image riding on a constant grey level or bias is placed in the collimated region. The energy spectrum of the transmittance function consists of a zero-order peak and two first-order peaks. If the spectrum formed by the integrating lens is measured with the scanning slit and photomultiplier assembly, intensity peaks corresponding to the zero-order and the two first-orders are observed. The magnitude of the first-order intensity is proportional to the magnitude of the sinusoidal image on the transparency. Since the magnitude of the sinusoidal variation is, in turn, proportional to the transducer input voltage, an examination of the energy spectrum provides a direct measure of the recorder system performance.

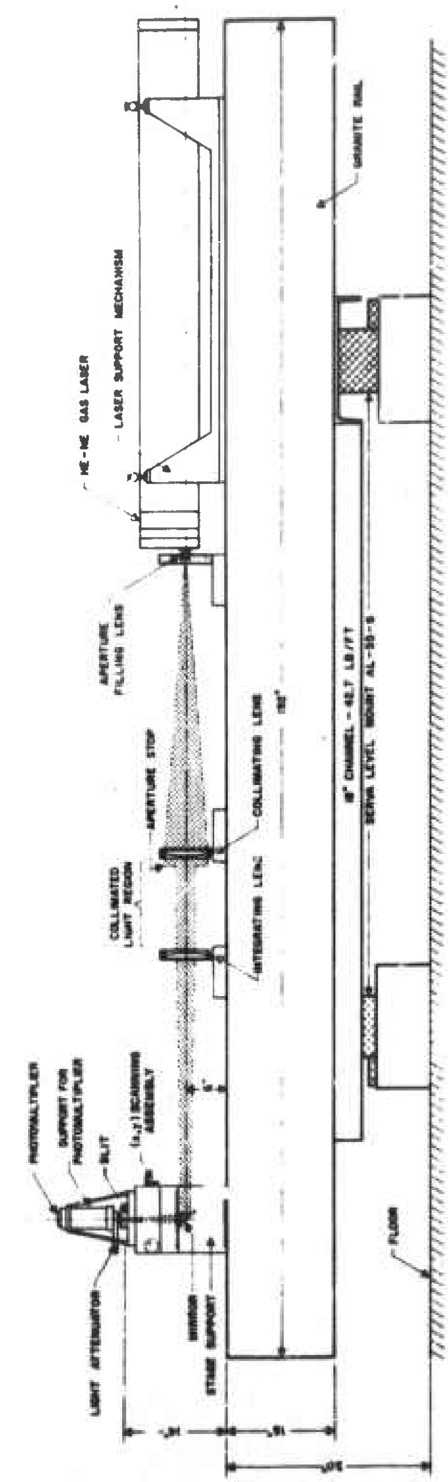

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FIG. 8 SKETCH OF OPTICAL SPECTRUM ANALYZER

In general, a transparency must be placed in a film gate when it is read out in an optical spectrum analyzer. The film gate serves two purposes: first, it keeps the transparency relatively flat by sandwiching it between high quality flat glass plates; and second, the introduction of a transparent matching liquid onto both surfaces of the transparency with the same index of refraction as the backing serves to eliminate the thickness variations present in the film. This removes spurious phase signals that are present in the transfer function of the photographic transparencies.

In order to select the best index-matching fluid for use in the film gate, the zero-order patterns of developed but unexposed film samples were examined on the film reader system as a function of the index of refraction of the matching fluid. It was found that for photographic film with Estar backing (Kodak film type 2479), the least distortion of the zero-order pattern was obtained with an index of refraction of 1.610. The transparent index-matching fluid is commercially known as Cargille fluid, and may be obtained with various values of index of refraction. Following this selection, all tests of photographic film on the film reader system were made using the film gate and the Cargille fluid with index of refraction equal to 1.610.

B. EXPERIMENTAL RESULTS

In order to test the overall linearity of the signal-recording process, first order intensity patterns generated with photographic recordings produced in the film recorder described in Sec. III were placed in the collimated region of the film reader. The intensity patterns were observed

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in detail with the scanning slit and photomultiplier assembly. The 3μ-wide slit was much narrower than the 21μ-peak-to-null width of the zero order intensity peak.

Figure 9 is a typical zero-order diffraction pattern for a developed film fog level, that is with no bias level or signal recorded. The pattern is symmetrical about the zero-order peak, has first minima 26 dB below the maximum peak and follows the theoretical envelope to within ± 1 dB. These results show that the film itself, mounted and properly matched in the liquid gate, introduces no significant errors into the diffraction pattern.

Figure 10 is a first-order intensity distribution for film with a recorded 6-volt, 20-MHz CW sinusoidal signal. Note that the light distribution near the main lobe is nearly ideal but that errors in the sidelobe envelope and null envelope are significant. It appears that these errors are caused by small perturbations in the recorded signals and in the film characteristics. For these preliminary investigations, patterns of this quality are quite adequate.

Figure 11 shows the first-order intensity patterns observed for different voltage inputs to the recorder system. Both coordinates in the figure are displayed in decibels, with the 0-dB voltage reference arbitrarily placed at 0.0937 volts, and the 0-dB intensity reference point arbitrarily placed at the peak of the largest signal. This figure shows that the recorder is linear within 1 dB for signals up to 3 volts rms. Also, if it is assumed that the 0.0937-volt signal represents the minimum useful input signal level, and that the maximum allowable amplitude distortion is 1 dB,

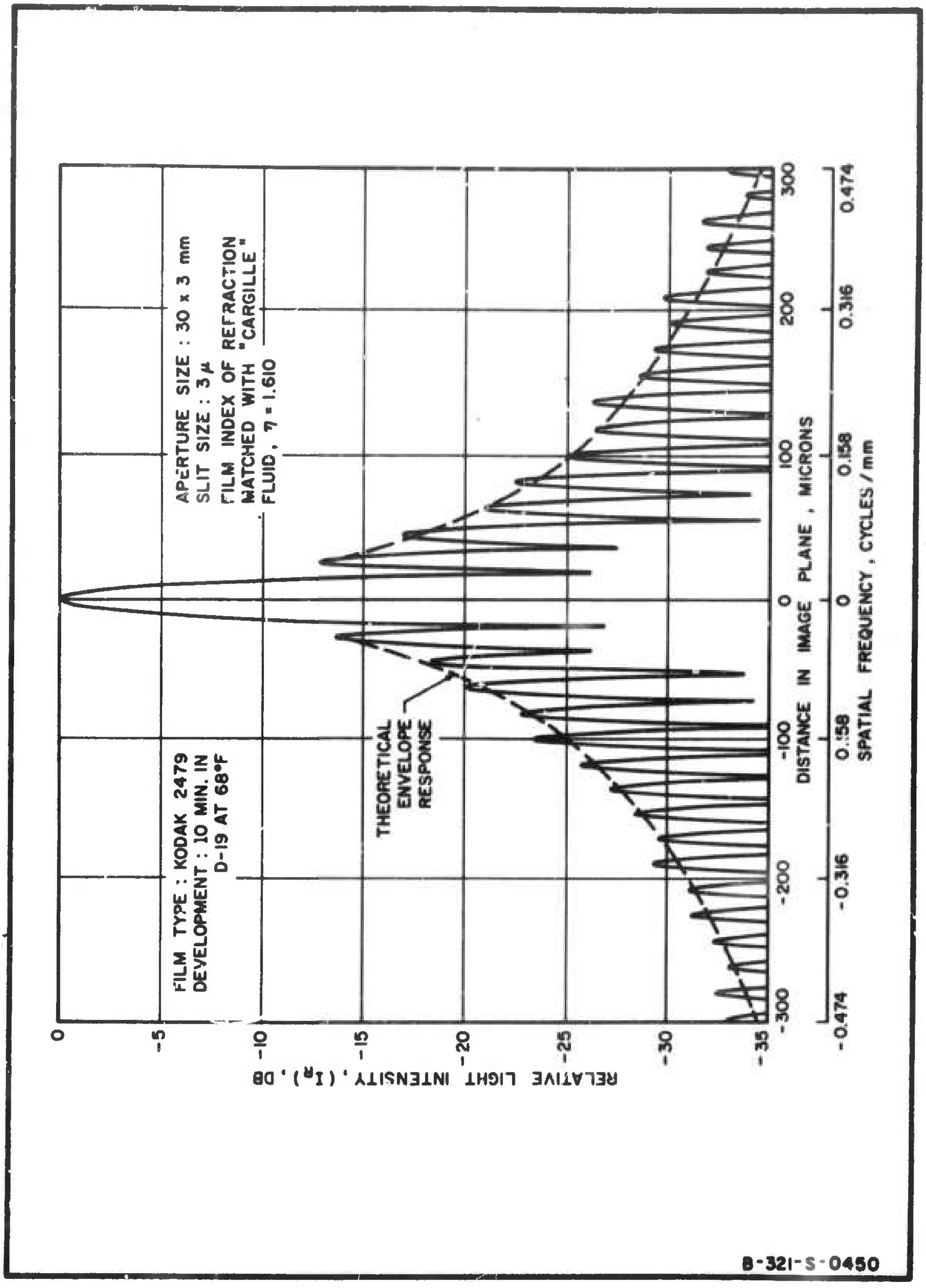

FIG. 9 ZERO-ORDER LIGHT INTENSITY DISTRIBUTION AT IMAGE PLANE FOR FILM " FOG " LEVEL

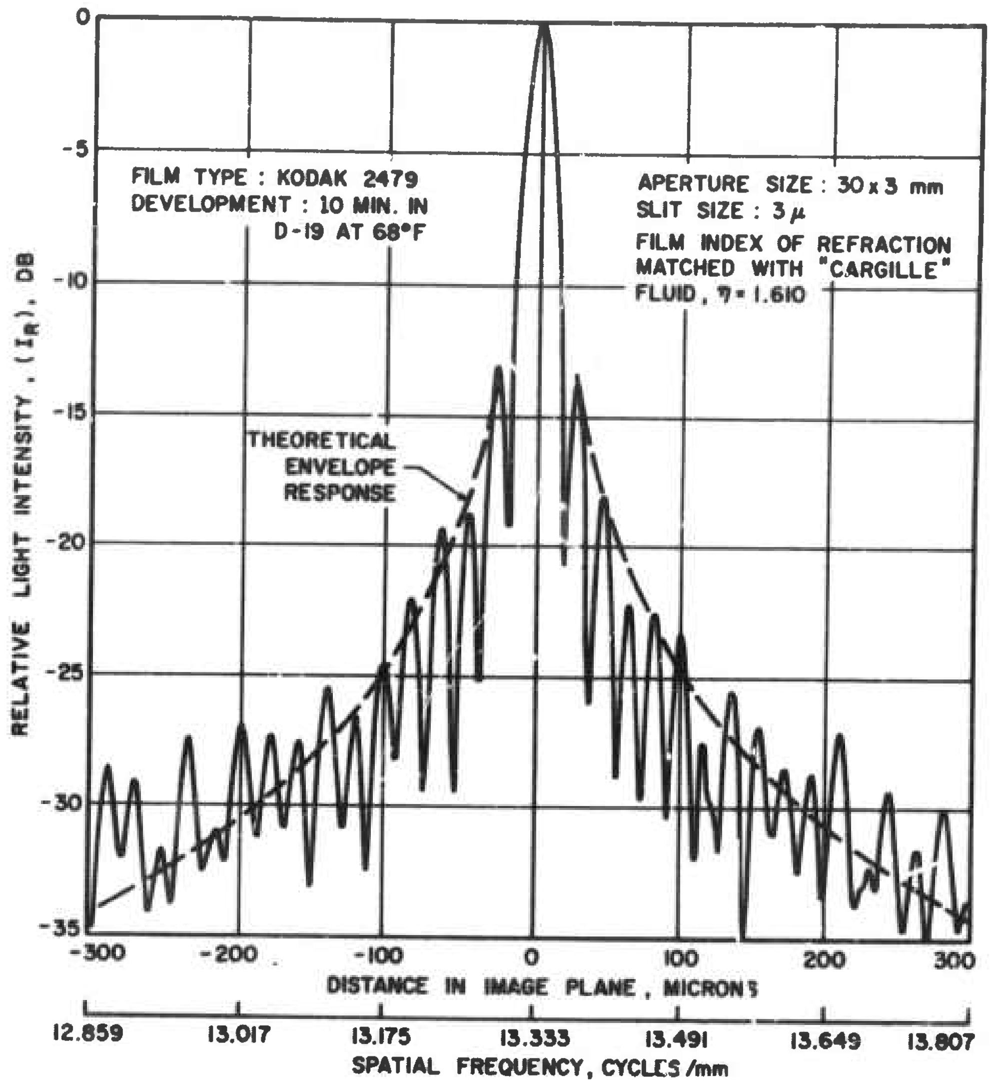

FIG. 10 FIRST ORDER LIGHT INTENSITY DISTRIBUTION AT IMAGE PLANE FOR FILM WITH A 6 VOLT SIGNAL

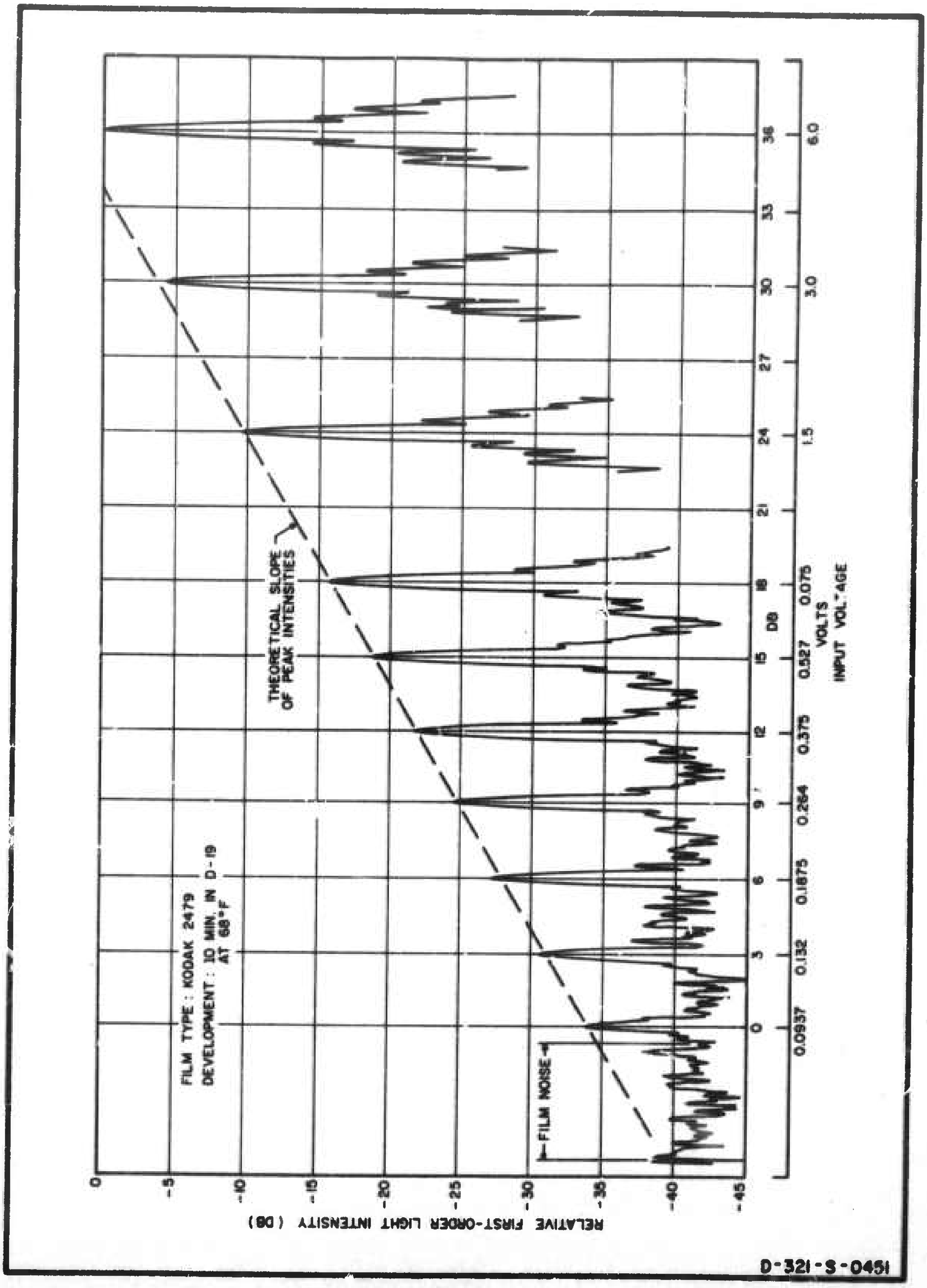

FIG. II FIRST-ORDER INTENSITY PATTERNS OBSERVED IN FILM READER SYSTEM FOR VARIOUS INPUT VOLTAGES TO THE RECORDER SYSTEM

then it is seen that the recorder has a 30-dB dynamic range. This result was obtained with 2479 film developed in D-19 for 10 minutes at 68-deg F. A later publication will present results obtained with other film types. The dependence of the linearity characteristic of Fig. 11 on parameters such as development procedure and film bias level will also be investigated in the future.

The film reader was used to study the grain-noise spectra of samples of 2479 film having different grey levels or intensity transmittances. The samples had no sinusoidal signals recorded on them. The intensity pattern was scanned with a 50μ wide slit in order to average out the lobe structure. Fig. 12 is a plot of log intensity in decibels vs spatial frequency obtained with no film sample in the collimated region. The scan was made for spatial frequencies up to 55.3 lines per mm (1/mm). Presently, our recorded sine waves have a spatial frequency of 13-1/3 1/mm. The light level observed in this measurement is the background level upon which any film noise must ride.

Figure 13 shows a similar scan obtained when a sample of film with intensity transmittance equal to 0.02 was placed in the collimated region of the film reader. Comparison with Fig. 12 shows that excess light intensity which may be attributed to film grain noise was detected. Similar results were obtained for other film samples. The ratio of average film noise intensity to zero-order intensity is a useful figure of merit for a photographic transparency since it is akin to the ratio of the noise power to that power which is available to the signal. In other words, it is not very impressive to have a low film noise power if in addition we also have such a low average film transmittance that little light power is available for diffraction from a recorded signal.

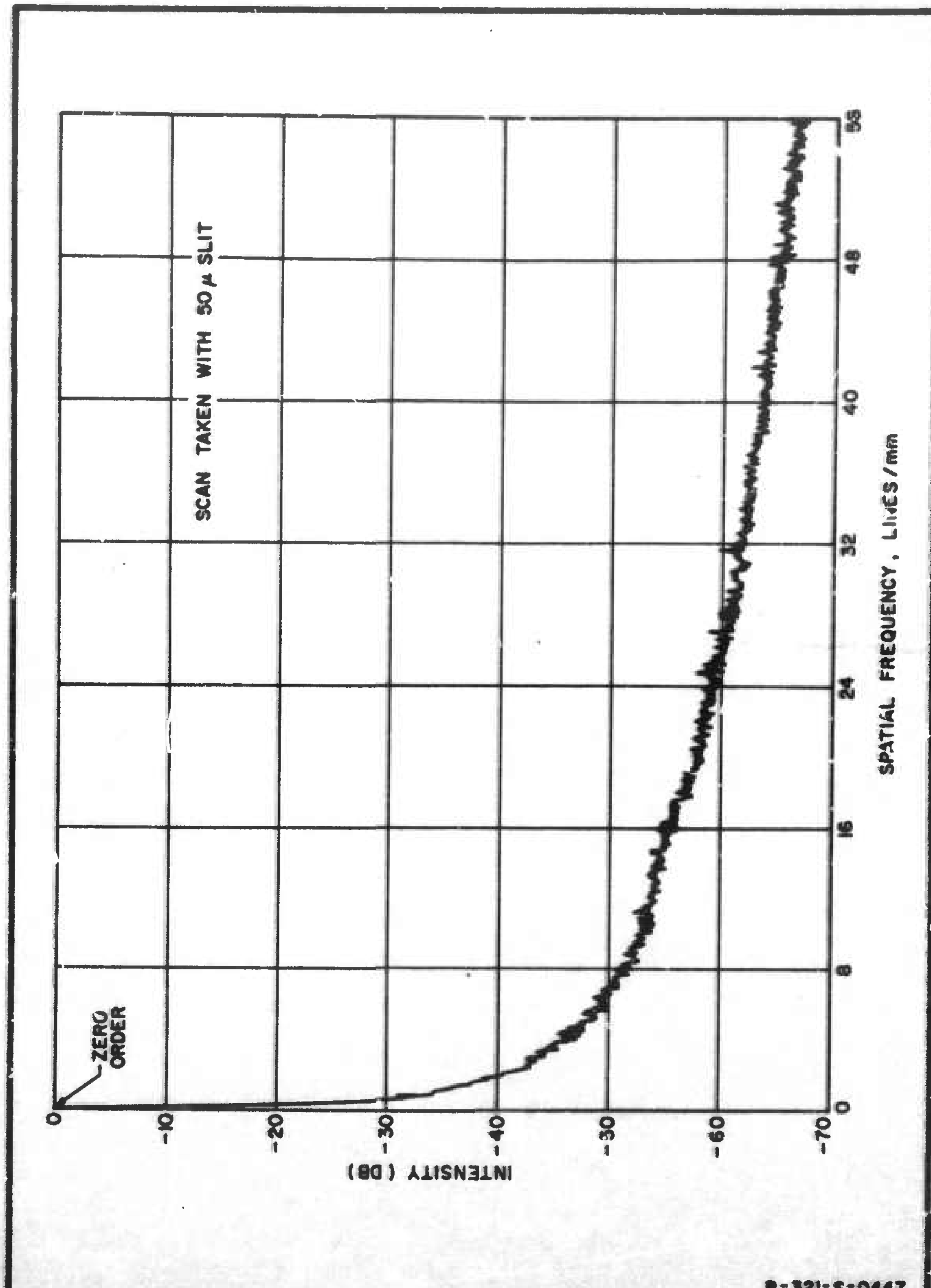

FIG. 12 SCAN OF INTENSITY vs. SPATIAL FREQUENCY WITH NO OBSTRUCTIONS IN SYSTEM

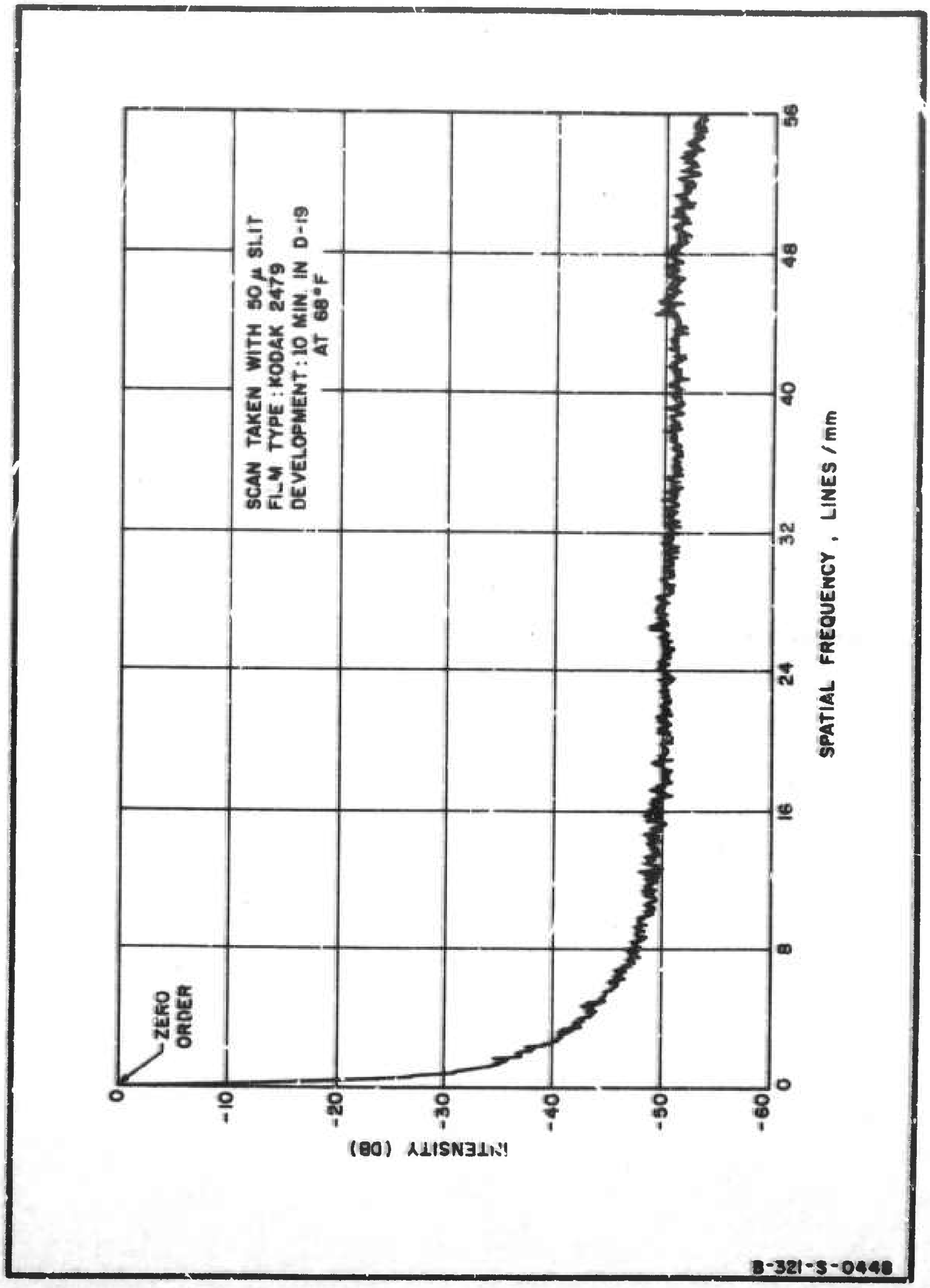

FIG. 13 SCAN OF INTENSITY vs. SPATIAL FREQUENCY FOR FILM WITH A 0.02 INTENSITY TRANSMITTANCE

A plot of film noise power normalized with respect to zero-order intensity vs average film transmittance is given in Fig. 14. Also drawn in this figure is a plot of absolute film noise power vs transmittance. This curve must be considered preliminary, as the accuracy of the noise measurements is not yet completely satisfactory. This curve leads us to conclude, at least tentatively, that over a substantial range of transmittance, the film noise power is constant. It should be noted in connection with this curve, that the intrinsic fog level of the 2479 film limits the maximum intensity transmittance in this set of noise experiments to 0.46.

Future work will include accurate measurement of grain-noise spectra for different film types, gray levels, etc. We will also attempt to clarify the implications of Fig. 14.

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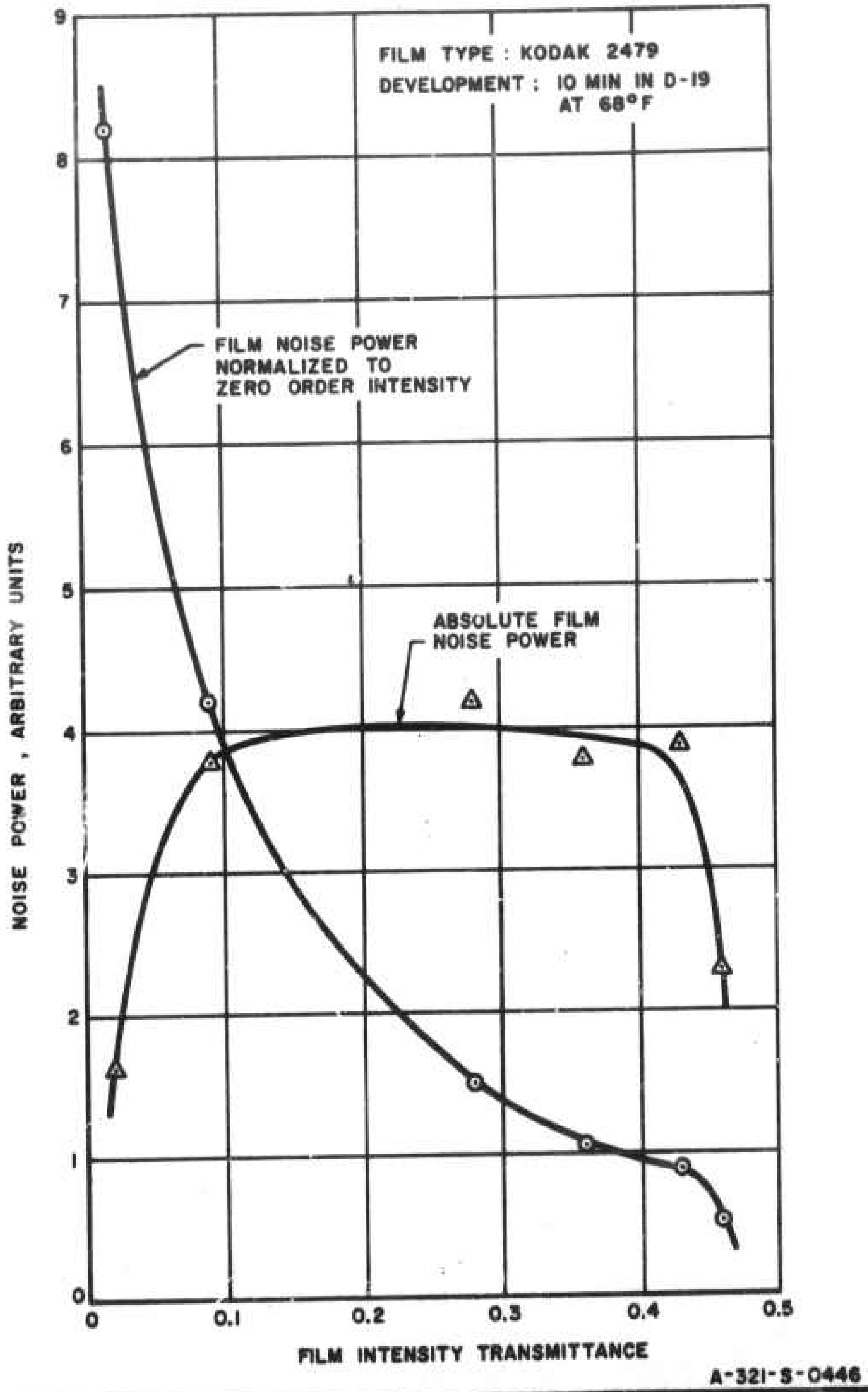

FIG. 14 FILM NOISE POWER vs. INTENSITY TRANSMITTANCE

V. REFERENCES

1. Aimette, A., Arm, M., King, M., and Minkoff, J., "Advanced Electro-Optical Signal Processing Techniques," Progress Report P-9/321, Electronics Research Laboratories, Columbia University, New York, N.Y. 10027, January 1, 1967, Unclassified.

2. Arm, M., and King, M., "Signal Processing Requirements for the Synthetic Spectrum Radar," Technical Report T-4/321, Electronics Research Laboratories, Columbia University, New York, N.Y. 10027, December 9, 1966, Secret.

3. Arm, M., and King, M., "Multichannel Electro-Optical Recorder for the Synthetic Spectrum Radar," Technical Report T-5/321, Electronics Research Laboratories, Columbia University, New York, N.Y. 10027, December 9, 1966, Unclassified.

4. Aimette, A., and Arm, M., "Electro-Optical Recorder for the Synthetic Spectrum Radar, Preliminary Experimental Results," Technical Report T-6/321, Electronics Research Laboratories, Columbia University, New York, N.Y. 10027, January 1, 1967, Unclassified.